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Laser Annealing of Refractory Ohmic Contacts in GaAs

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Laser annealing has been successfully applied in producing low resistance ohmic contact to GaAs using refractory metallizations. These alloy systems include TiW, Ta, Mo, and Ni deposited on epitaxial Ge layers grown on (100) n-type GaAs substrates. In some cases an N^+ layer obtained by ion implantation was present at the GaAs surface. Ohmic contact resistances of $1\text{-}5 \times 10^{-6}\ \Omega cm^2$ have been produced by laser annealing. These values compare favorably with the results obtained by thermal annealing. The refractory ohmic contacts reported here are intended to improve the reliability of devices operated under high-temperature and/or high-power conditions.

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CONTENTS

LASER ANNEALING OF REFRACTORY OHMIC CONTACTS TO GaAs

INTRODUCTION

The use of lasers for annealing elemental and compound semiconductor materials has now become a widespread technique. An extensive review of this technique is given by A. E. Bell[1]. This method offers singular advantages over the currently employed thermal annealing method, when it is desired to anneal small and selected areas of a semiconductor without subjecting the entire substrate to thermal cycling. An obvious application of this feature of laser annealing is the anneal of small metallic contacts on a semiconductor surface.

Recent studies initiated at NRL[2-4] have been concerned with thermal annealing of refractory ohmic contacts to GaAs. These alloy systems include TiW/Ge, Ta/Ge, Mo/Ge and Ni/Ge. The ohmic contacts produced using these refractory materials have high-temperature reliability applications and applications to devices which experience high channel and contact temperatures such as power field-effect transistors (FET) and planar transferred-electron devices (TED). High-temperature reliability has been demonstrated, for example, by TiW/epi Ge/implanted Si/GaAs ohmic contacts, which retain low resistance when annealed up to 500°C for 195 hr. This is an improvement over conventional AuGe/GaAs ohmic contacts which show an increase in resistance after 25 hrs at 350°C.

EXPERIMENTAL METHOD

Laser annealing of four different refractory-metal contacts has been investigated: TiW (88 wt % W, 12 wt % Ti), Ta, Mo, and Ni. Figure 1 depicts the geometry of typical refractory ohmic contacts to GaAs. The metallizations were deposited on an epitaxial Ge layer grown on (100) n-type epitaxial GaAs with carrier concentrations of 10^{16} to $10^{17}/cm^3$. The epitaxial GaAs layers are typically grown on N^+ substrates. Refractory metal contacts were deposited on the top surface by electron-beam evaporation or sputtering. Circular contact patterns with diameters of 50 to 250 µm were formed by etching. Ohmic contact to the N^+ backside was formed using AuGe/Ni.

Laser annealing of the contacts was carried out using a ruby laser which can emit a one joule, 22 nsec pulse obtained by Q-switching the optical cavity by means of a Pockels' cell. Figure 2 shows a schematic of the two annealing configurations employed in these studies. In one configuration, a single TEM_{oo} mode beam was obtained by placing a 0.8 mm circular aperture in the optical cavity. This uniform output beam was focused to form a 30 to 250 µm diameter spot on the circular metallic contact surface. The 30 µm spot was obtained by placing a metal mask on top of the metallic contact. For the second configurtion, the full multi-mode one joule output from the laser was homogenized by a 1.2 cm diameter fused quartz optical waveguide which was bent and tapered to produce a 0.7 cm diameter spot at the sample. This configuration allowed larger areas of a speciman to be irradiated with a nearly uniform irradiation pattern.

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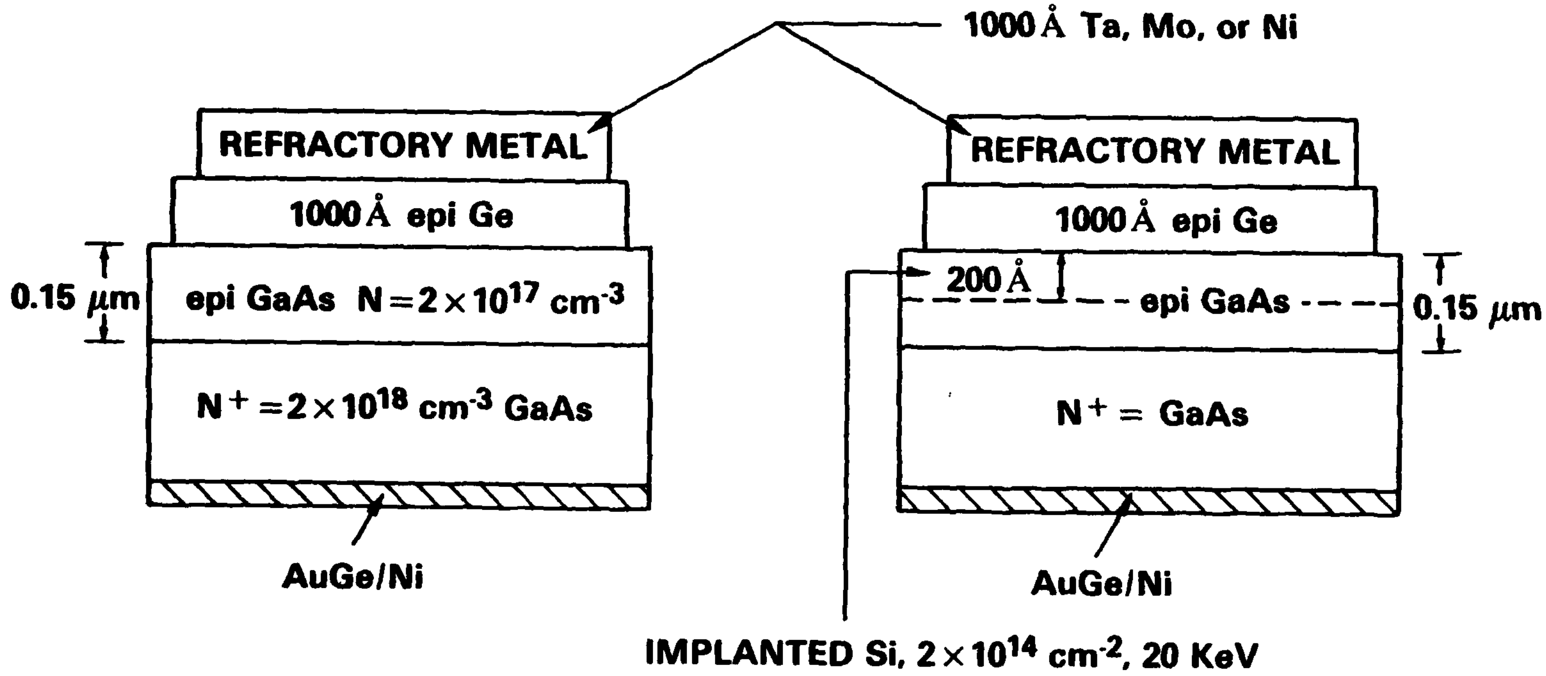


Figure 1. Schematic of a typical refractory ohmic contact to GaAs.

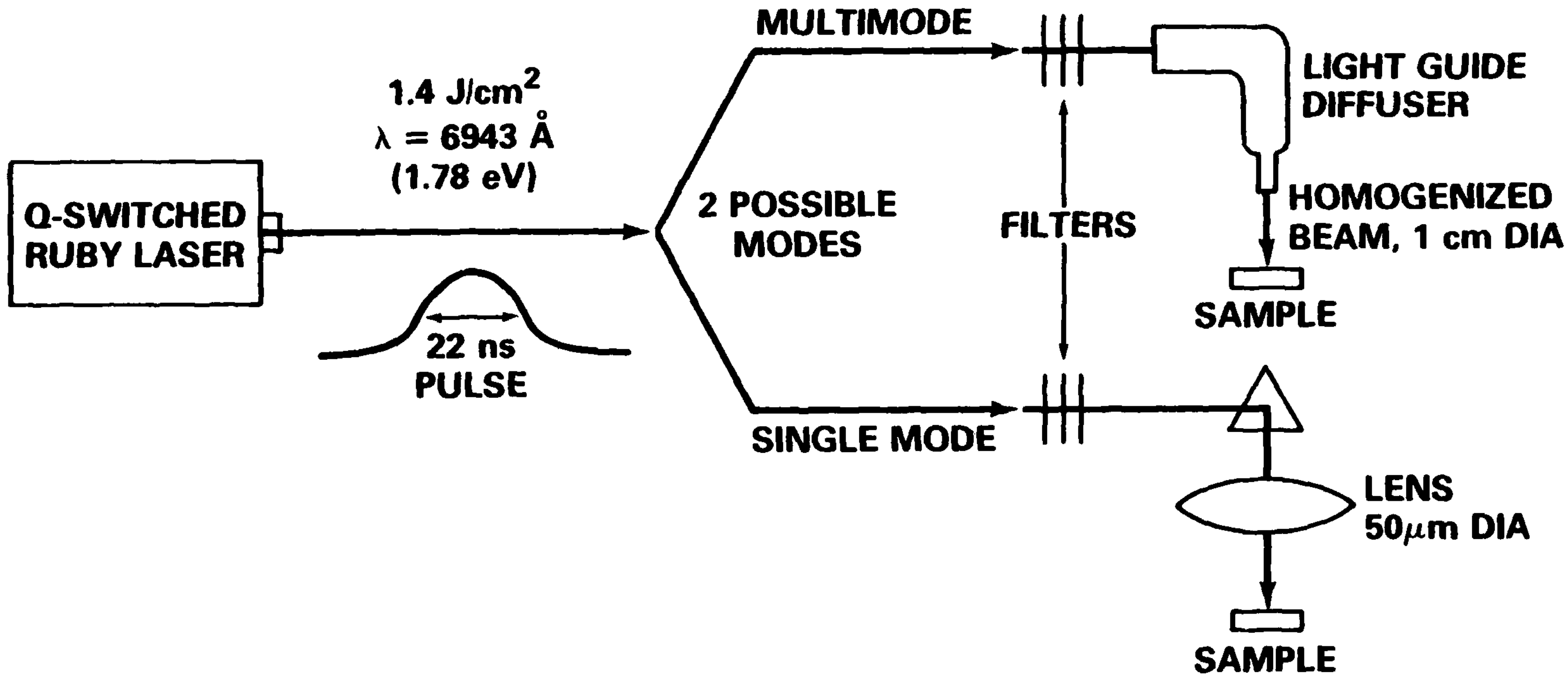


Figure 2. Schematic of the pulsed ruby laser system used to anneal refractory metallic contacts. Two possible modes of operation are displayed.

The transition from Schottky barrier to ohmic contact is illustrated in Fig. 3, which shows current/voltage (I/V) characteristics before ohmic contact was obtained (left) and after sufficient laser energy density to form ohmic contact (right). The top curve in the left figure shows reverse bias conditions, the contact is still rectifying after irradiation at 0.13 J/cm^2 with a reverse breakdown voltage of about 8 volts. In the right figure, ohmic contact is confirmed by the linear I/V characteristic.

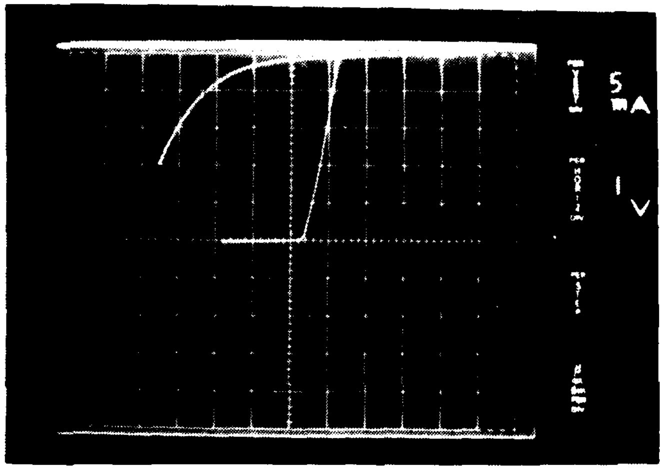
Experimental curves of the specific contact resistance versus laser energy density obtained for the alloy systems Ni/Ge-GaAs, Ta/Ge-GaAs and Mo/Ge-GaAs are shown in Fig. 4. These results were obtained using the TEM_{00} laser configuration, with a 50 μm mask placed over 250 μm metal contacts. The mask confined the laser beam to the metallic contact region. Approximate melting points for each of these metallizations are shown at the top of Fig. 4. The melting points were determined from photomicrographs of the irradiated surfaces.

DISCUSSION

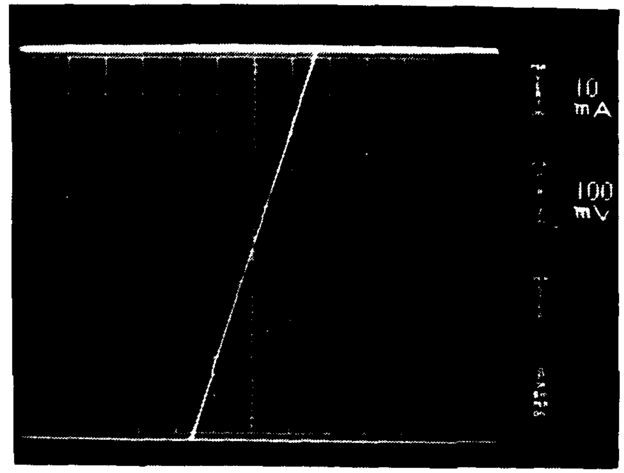
The occurrence of a minimum value for the specific contact resistance, shown in Fig. 4., can tentatively be explained in terms of an ionic migration model according to which Ge ions migrate into a shallow surface layer to create a high donor doping concentration. Using Auger sputter profiling techniques, extensive Ge migration into GaAs has been observed for both thermal-annealed and laser-annealed Ni/Ge/GaAs ohmic contacts. It has been shown that the migration is greatly enhanced by alloying between the Ge, metal, and GaAs[(2)]. Low contact resistance occurs by electrons tunneling between the top metal and the highly doped surface layer in the GaAs. At low laser energy density, the contact resistance is high, but it begins to fall at higher energy densities as Ge migration occurs. A minimum is reached at some optimum doping level. As the energy density is further increased above that required to melt and alloy the top metal and Ge layer, metal and Ge atoms are lost from the surface by evaporation, as was found by electron microprobe x-ray analysis. Presumably, this loss of metal and Ge results in reduced Ge migration at the GaAs surface.

SUMMARY

High-reliability, low-resistance, ohmic contacts to n-type GaAs have been developed using laser annealing of contacts consisting of a combination of epitaxial Ge, ion implantation, and refractory metallizations. These contacts have high-temperature and high-power device-reliability applications. The refractory metallizations which have been studied include TiW, Ta, Mo, and Ni. Auger sputter profiles show that ohmic contact is accompanied by extensive Ge migration into the GaAs. The measured specific contact resistance to n-type GaAs doped to $2X10^{17}$ cm^{-3} for laser annealed ohmic contacts ranged between $1\text{-}5X10^{-6}$ $\Omega\text{-}cm^2$. These results compare favorably with thermal-annealed refractory ohmic contacts.



0.13 J/cm^2
VERT: 5mA/div
HOR: 1V/div



1.5 J/cm^2
VERT: 10 mA/div
HOR: 100 mV/div

Figure 3. Curve tracer I-V curves for Ta/Ge-GaAs laser annealed refractory contacts, measured after laser annealing at energy densities of 0.13 J/cm^2 and 1.5 J/cm^2.

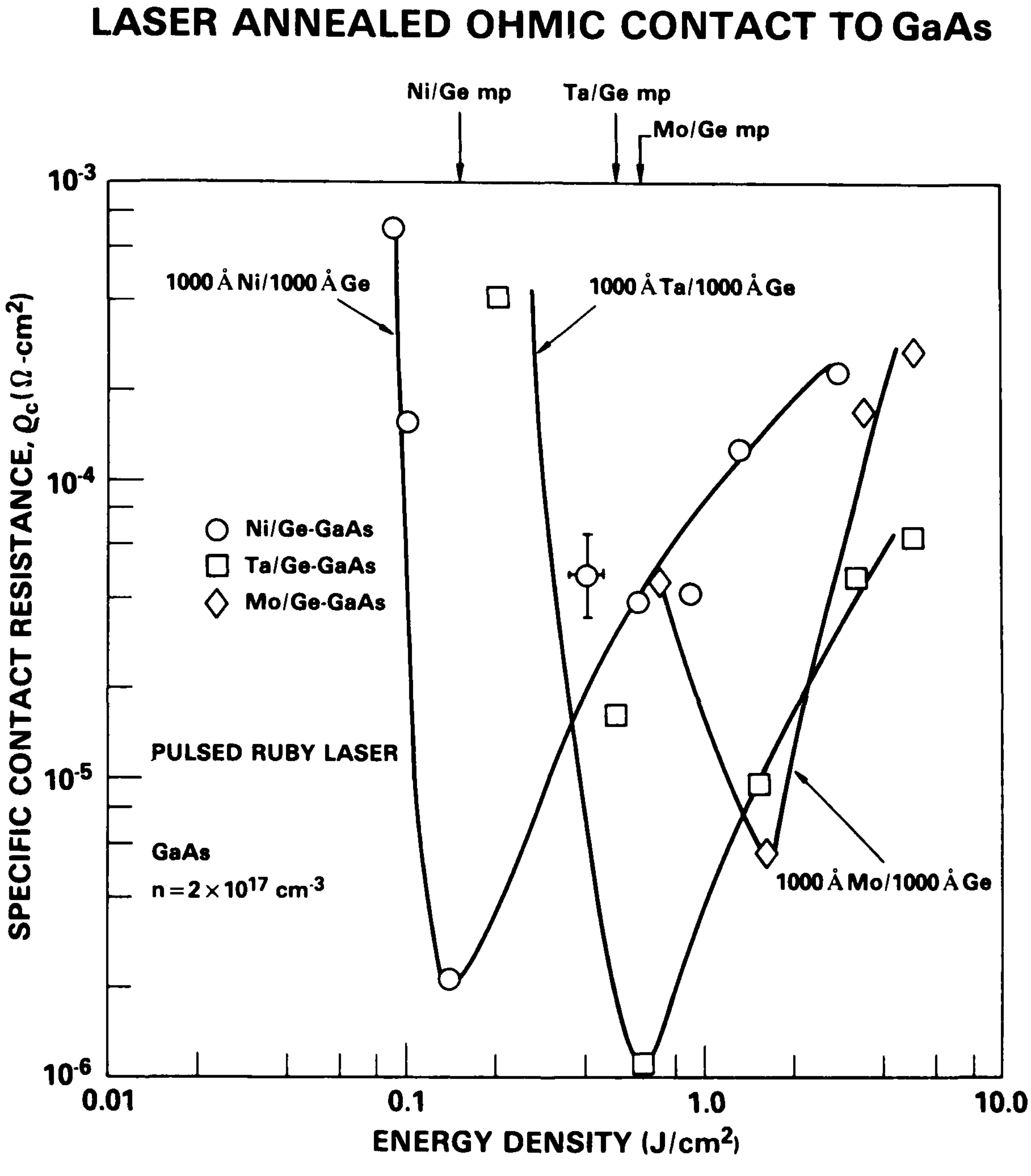


Figure 4. Plot of the specific contact resistance (Ω-cm^2) versus pulsed-laser energy density (J/cm^2) for Ni/Ge, Ta/Ge, and Mo/Ge contacts on n-type GaAs; mp represents the melting points of the various alloy surfaces as determined from surface photomicrographs.

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